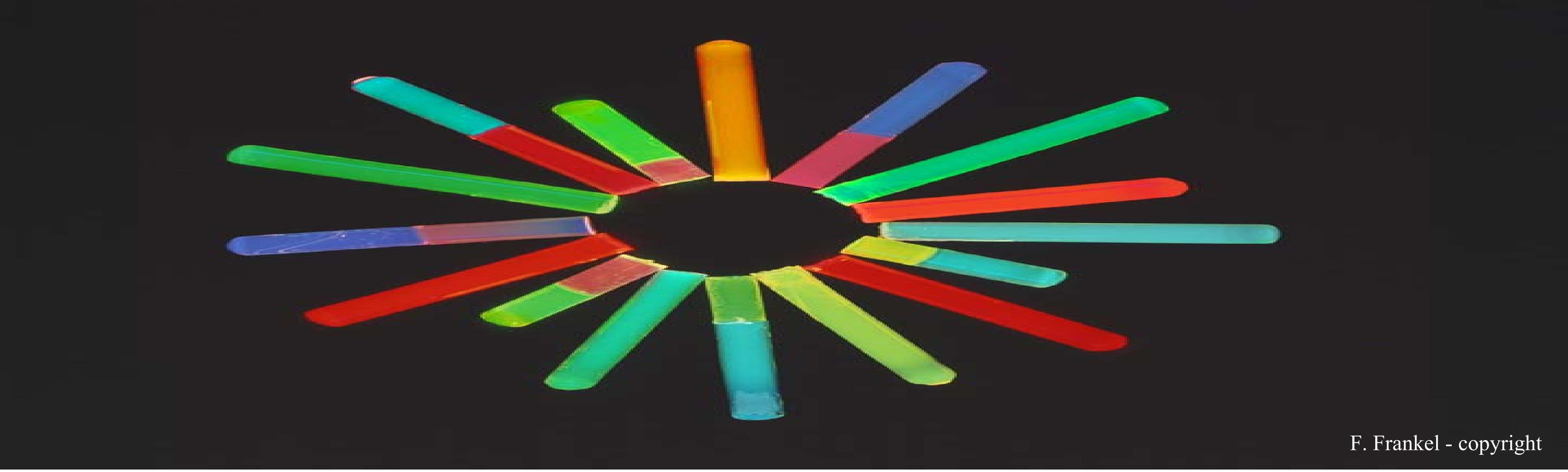
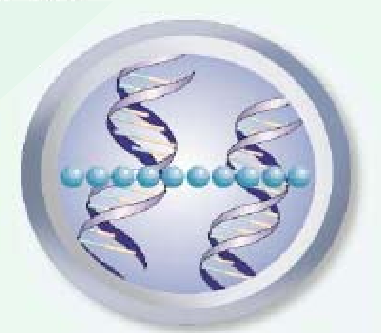


Overview of the National Nanotechnology Initiative

M.C. Roco
Senior Advisor for Nanotechnology, NSF
Chair, Subcommittee on Nanoscience, Engineering and Technology (NSET),
National Science and Technology Council (NSTC)

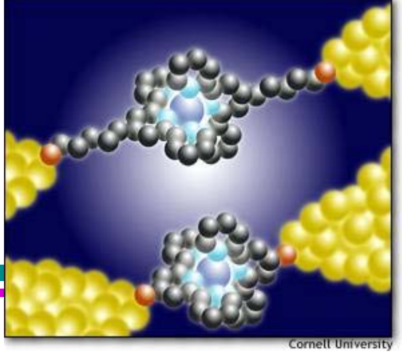
- **NNI motivation and timeline**
- **Overview of NNI, and planning for the next 5 years**
- **International perspective**
- **NNI areas of focus and partnerships**

PCAST, WH. September 10, 2003



Nanotechnology

Definition on www.nano.gov/omb_nifty50.htm (2000)



- Working at the atomic, molecular and supramolecular levels, in the length scale of approximately 1 – 100 nm range, in order to understand and create materials, devices and systems with fundamentally new properties and functions because of their small structure

- **NNI definition encourages new contributions that were not possible before.**

  - novel phenomena, properties and functions at nanoscale, which are nonscalable outside of the nm domain

  - the ability to measure / control / manipulate matter at the nanoscale in order to change those properties and functions

  - integration along length scales, and fields of application

Why moving into nanoworld ?
A. Intellectual Drive

- **Miniaturization is of interest**
  - Less space, faster, less material, less energy

More important:

- **Novel properties/ phenomena/ processes**
  - New structures and functions; Engineering beyond nature
- **Unity and generality**
  - At the building blocks of all natural/artificial things; Systems!
- **Most efficient length scale for manufacturing**
  - Less energy than for subatomic or macroscopic
- **Transcendent effects: at the confluence of steams**
  - S&T; Living/non-living ; Interdisciplinarity; Relevance areas

It requires a grand coalition, cooperative national program
Cross-cutting, precompetitive, with broad societal implications

B. Broad societal implications

(examples of societal implications;
worldwide estimations made in 2000, NSF)

- **Knowledge base**: better comprehension of nature, life

- **New technologies and products: ~ $1 trillion / year by 2015**
(With input from industry US, Japan, Europe 1997-2000, access to leading experts)

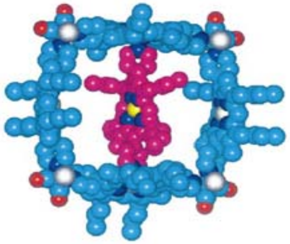
Materials beyond chemistry: $340B/y
Pharmaceuticals: $180 B/y
Aerospace about $70B/y
Electronics: over $300B/y
Chemicals (catalysts): $100B/y
Tools ~ $22 B/y

Est. in 2000 (NSF) : about $40B for catalysts, GMR, materials, etc.
Est. in 2002 (DB) : about $116B for materials, pharmaceuticals and chemicals

Would require worldwide ~ 2 million nanotech workers

- **Improved healthcare**: extend life-span, its quality, physical capabilities

- **Sustainability**: agriculture, food, water, energy, materials, environment; ex: lighting energy reduction ~ 10% or **$100B/y**



C. Timeline for beginning of industrial prototyping and commercialization

Accidental nanotechnology: since **1000s yr** (carbon black)

Isolated applications (catalysts, composites, others) since **1990**

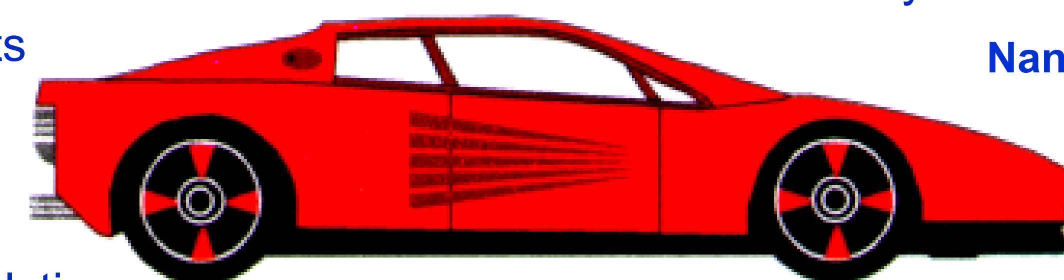
- **First Generation: passive nanostructures**
  in coatings, nanoparticles, bulk materials (nanostructured metals, polymers, ceramics):
  ~ 2001 –
- **Second Generation: active nanostructures**
  such as transistors, amplifiers, targeted drugs and chemicals, actuators, adaptive structures:
  ~ 2005 –
- **Third Generation: 3D nanosystems**
  with heterogeneous nanocomponents and various assembling techniques; bio-assembling; networking at the nanoscale and new architectures
  ~ 2010 –
- **Fourth Generation: molecular nanosystems**
  with heterogeneous molecules, based on biomimetics and new designs
  ~ 2020 (?) -

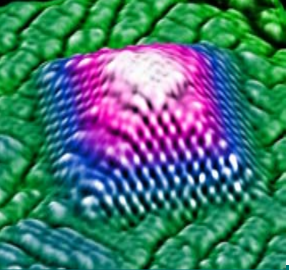
Example:

Applications of various nanostructures in a car

Sample of companies involved: GM, Ford, Toyota, Mitsubishi, BMW, all tire companies: there is no major part of car that has not yet been affected by nanotechnology (2003)

Ex: "Nano in Cars" consortium in Germany - 6 car manufacturers, 10 suppliers, and 26 R&D university and laboratories



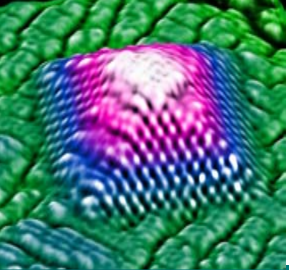


NATIONAL NANOTECHNOLOGY INITIATIVE – *from vision to the investment strategy*

- Timeline (Preparing NNI) -

- March 1991 — "Nanoparticle Synthesis and Processing" (NSF program)
- Nov. 1996 — Nanotechnology Group (bottom-up)
- March 1998 — Functional Nanostructures; Partnership in nanotechnology (NSF in collaboration with other agencies)
- **Sept. 1998** — **NSTC establishes Interagency Working Group of Nanoscience and Engineering (IWGN)**

- March 1999 — OSTP/CT presentation on NNI, Indian Treaty Room
- May-Sept. 1999 — Congress hearings; Three publications NSTC/IWGN;
  Nanotechnology R&D planning in six agencies
  IWGN planning for NNI
- Oct. – Dec. 1999 — OMB review – NNI the only new topic recommended
  PCAST – Letter to the President supporting NNI
  OSTP and WH Approval
- **Jan. 2000** — **NNI announced by the President in Jan 2000**



NATIONAL NANOTECHNOLOGY INITIATIVE – *from vision to the investment strategy*

- Timeline (FY 2001-2003) -

- **Feb. – Dec.. 2000** — **WH, Congress review and approve FY 2001 NNI**
  6 agencies; actual investment $465M
  Concerns about the interest, "science fiction"
  "Societal Implications" workshop in Sept. 2000
- **Feb. – Dec. 2001** — **WH and Congress approve FY 2002 NNI**
  12 agencies; actual investment $697M
  International reaction: programs in 30 countries
  Industry get involved in many sectors
  20 states and regional alliances begin to invest
- **Feb. –Dec. 2002** — **WH and Congress approve FY 2003 NNI - both sides**
  16 agencies ; Current plan - $770M
  Outcomes: research, education, industry and states investments, patents, IPO; GMO perspective
  Letter from OSTP-OMB with NNI as a priority
- **Feb. –Dec. 2003** — **WH Request - $849M; 2 Bills in Congress for FY04-08**

Defining the vision and implementation plan

National Nanotechnology Initiative

1999: 10-year vision

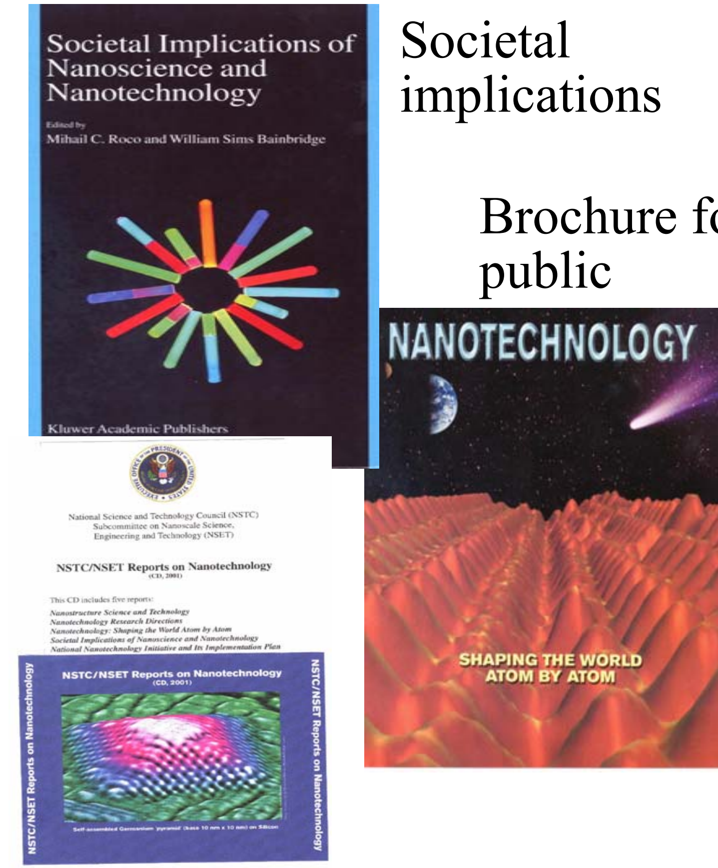
Government plan

Worldwide benchmark

Reports

Societal implications

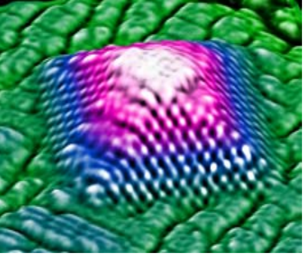
Brochure for public



Planning with feedback after each: 5 years, 1 year, 1 month; and various levels: national/NSET, agency, program

In preparation: Topical reports; new 2004:10 year vision

MC. Roco, 9/10/03



Planning for the future: expanding the frontiers of nanotechnology

Workshops for receiving input from the community (examples):

- Nanostructured materials "by design" - Workshops on 10/02, 06/03
- Catalysts that function at the nanoscale - Workshop on 06/03
- Nanoelectronics, optoelectronics and magnetics - Workshops 11/02, Fall 03
- CBRE protection and detection (revised in 2002) - Workshop 05/02
- Advanced healthcare, therapeutics, diagnostics - Workshops 06/00
- Nano-biology and medicine – Workshop Fall 03
- Environmental improvement - Workshops 06/02, 08/02, Spring 03
- Efficient energy conversion and storage - Workshops 10/02, 01/03
- Microcraft space exploration and industrialization - Workshop Fall 03
- Manufacturing processes - Workshops 01/02, 05/02
- Agriculture and food systems – Workshop 11/02
- Societal implications (II) - Workshop 12/03

"Nanotechnology Research Directions (II)" - 2004

Revisit the NNI long-term vision formulated in January 1999

Organizations that have prepared and contribute to the National Nanotechnology Initiative (**NNI**)

Presidential Council of Advisors in Science and Technology (PCAST)

White House

Office of Management and Budget (OMB)

Office of Science and Technology Policy (OSTP)

National Science and Technology Council (NSTC)

IWGN (October 1998-August 2000)

NSET (August 2000 - continuing)

Departments

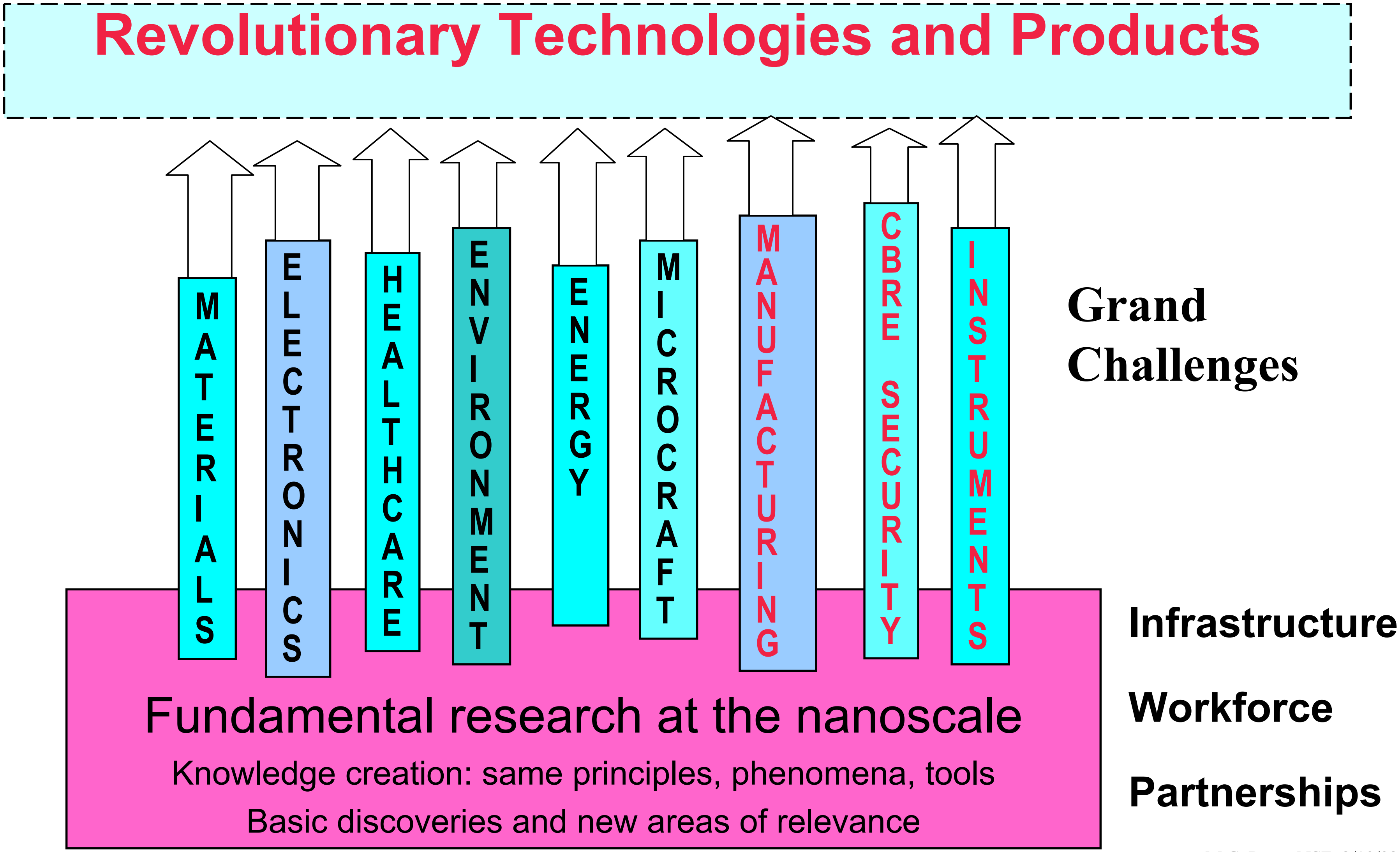
DOC/NIST, DOD, DOE, DOJ, DOS, DOT, DOTreas, DHS, USDA

Independent Agencies

EPA, FDA, NASA, NIH, NRC, NSF, USG

Estimation:		
	Federal Government R&D funding	NNI (~$700M in 02)
	Industry (private sectors)	~ NNI funding
	State and local (universities, foundations)	~ 1/2 NNI funding

Interdisciplinary “horizontal” knowledge creation vs. “vertical” transition from basic concepts to Grand Challenges



Elements of NNI

- **Fundamental Research**
  Provides sustained support to individual investigators and small groups doing fundamental, innovative research
- **Grand Challenges**
  for research on major, long-term objectives
- **Centers and Networks of Excellence**
  for interdisciplinary research, networking, industry partnerships
- **Research Infrastructure**
  metrology, instrumentation, modeling/simulation, user facilities
- **Societal Implications and Workforce Education and Training**
  for a new generation of skilled workers; the impact of nanotechnology on society: legal, ethical, social, economic
  (* these budgets do not include education and training through research grants)

NNI: R&D Funding by Agency

Fiscal year (all in million $)	*2000*	*2001* Enacted/actual	*2002* Enacted/actual	*2003*	*2004* Request
National Science Foundation	97	**150** /150	**199** /204	221	249
Department of Defense	70	**110** /125	**180** /224	243	222
Department of Energy	58	**93** /88	**91.1** /89	133	197
National Institutes of Health	32	**39** /39.6	**40.8** /59	65	70
NASA	5	**20** /22/	**35** /35	33	31
NIST	8	**10** /33.4	**37.6** /77	66	62
Environmental Protection Agency	-	/5.8	**5** /6	5	5
Homeland Security (TSA)	-		**2** /2	2	2
Department of Agriculture	-	/1.5	**1.5** /0	1	10
Department of Justice	-	/1.4	**1.4** /1	1.4	1.4
TOTAL	270.0	**422.0** /464.7	**~ 600** /697	~ 770	~ 849

Other NNI (NSET) participants are:
OSTP, NSTC, OMB, DOC, DOS, DOT, DOTreas, FDA, NRC, DHS, IC

Requested FY 2004 NNI Investment by Agency

FY04 (preliminary distribution)	NNI total	DOD	DOE	DOJ	DHS	EPA	NASA	NIH	NIST	NSF	USDA
Fundamental Research	**278**	**26**	**57**				**10**	**28**		**152**	**5**
Biosystems	69	6	4				5	28		21	5
Phenomena, structures, and tools	105	18	28				1			58	
Devices and systems	44		14				2			28	
Theory, modeling, and simulation	30		6				2			22	
Environmental knowledge	14		4							10	
Manufacturing knowledge	14		1							13	
Grand Challenges	**301.4**	**143**	**42**	**1.4**	**2**	**5**	**9**	**39**	**45**	**10**	**5**
Nanostructured Materials by Design	66.4	37	16	0.4			3		7	2	1
Nanoelectronics, Optoelectronics, Magneti	104.5	89	8	0.5			3		3	1	
Advanced Healthcare, Therapeutics	40							39		1	
Environmental Improvement	11		4			5				1	1
Energy Conversion/Storage	12	2	10								
Microcraft & Robotics	3						3				
CBRE Protection/Detection (was Bionanoc	22	15	0.5	0.5	2					2	2
Instrumentation & Metrology	31		2						28	1	
Manufacturing Processes	11.5		1.5						7	2	1
Centers/Networks	**106**	**46**	**2**				**12**			**46**	
Infrastructure*	**145**	**5**	**96**					**2**	**14**	**28**	
Societal and Education**	**19**	**2**						**1**	**3**	**13**	
TOTAL	**849.4**	**222**	**197**	**1.4**	**2**	**5**	**31**	**70**	**62**	**249**	**10**

Scientific Breakthroughs
in the first three years (NNI, 2001-2003)

- **Developments faster than expected**

  Reducing the time of reaching commercial prototypes by at least of factor of two for several key applications

- **10 key advancements**
  - Engineer materials with atomic precision using biosystems as agents
  - Create circuits with the logic element a molecule wide
  - Assemble DNA, nanocrystals to build molecular devices and systems
  - Detect anthrax, other contaminants with unprecedented speed
  - Single molecule behavior and interaction
  - Artificial genetic system
  - Conducting polymers
  - New concepts for large scale production of nanotubes, their use
  - Drug delivery systems
  - Detection of cancer

Grand Challenges (NNI, FY 2002)

● Nanostructured materials "by design" (NSF lead)	~ 22%
● Nanoelectronics, optoelectronics and magnetics (DOD lead)	**39%**
● Advanced healthcare, therapeutics, diagnostics (NIH lead)	8%
● Environmental improvement (lead EPA and NSF)	4%
● Efficient energy conversion and storage (DOE)	5%
● Microcraft space exploration and industrialization (NASA lead)	3%
● CBRE Protection and Detection (revised in 2002) (DOD lead)	7%
● Instrumentation and metrology 9NIST and NSF lead)	6%
● Manufacturing processes (NSF and NIST lead)	5%

(details in the NNI Implementation Plan, http://nano.gov)

Key areas of relevance in FY 2004 Request

(single counted, without cross-cutting, all in $ million)

● Materials	141
● Electronics	179
total 320	
● Energy	12
● Environment	25
total 37	
● Bio-medical	109
● Societal and Educational Implications	19
total 138	

Revolutionary technologies, products and services

- **Growing area**
  - Materials, including bulk, coating, dispersed systems
  - Chemicals, including catalysts
  - Pharmaceuticals
  - Electronics
- **Emerging areas**
  - Nanomedicine
  - Energy conversion and storage
  - Agriculture and food systems
  - Molecular architectures
  - Realistic multiphenomena/multiscale simulations
  - Environmental implications
  - Improving human performance

Centers and networks

<u>Overall: 22 new large centers and networks supported by NNI since 2001</u>

- 10 NSF (8 NSECs, 2 networks)
- 5 DOE (including 6 national labs) – large R&D facilities
- 3 DOD (including Soldier Nanotech at MIT in 2002)
- 4 NASA (at universities in 2002)

Examples of academic-based networks (NSF)

New since 2001

- **Network for Computational Nanotechnology** (NCN)
  7 universities (Purdue as the central node)

- **National Nanotechnology Infrastructure Network**
  User facility
  Development measuring & manufacturing tools
  Education and societal implications

- **Oklahoma Nano Net (EPSCoR award)**

Nanotechnology in the world

Comparison for industrialized countries 1997-2002

Estimated government sponsored R&D in $ millions/year

using NNI nanotechnology definition (without MEMS, other microstructures)

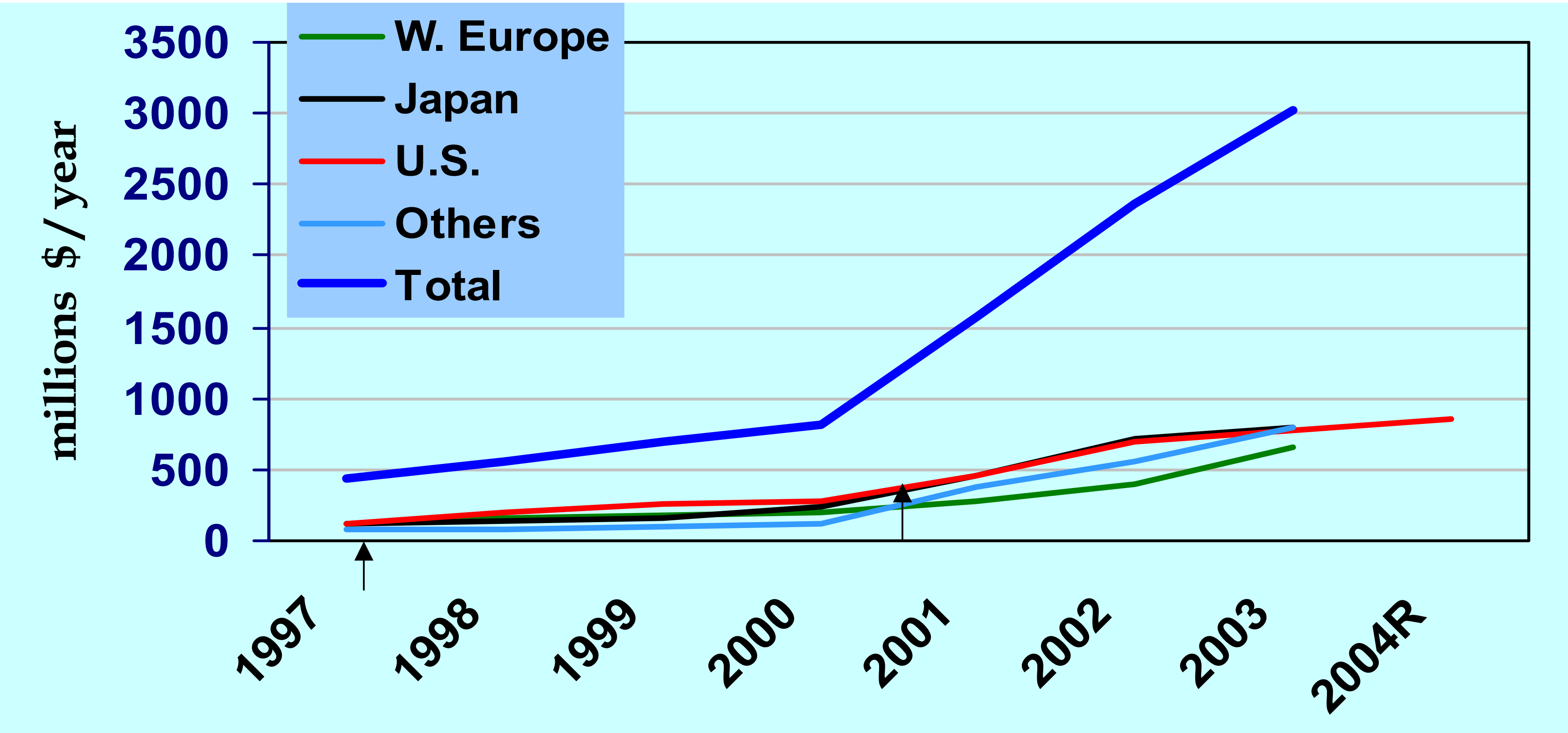
Fiscal Year	1997	2001	2002	2003	2004R
W. Europe	126	~ 225 (270)	~ 400	~ 650	
Japan	120	465	~ 720	~ 800	
USA	116	422 (465)	~ 600 (697)	770	849
Others	70	~ 380	~ 550	~ 800	
Total	***432*** 100%	***1492 (1580)*** 365%	***2250 (2367)*** *547%*	***3020*** *700%*	***849***

Others: Australia, Canada, China, E. Europe, FSU, Israel, Korea, Singapore, Taiwan

Note: ( ) Actual budget

Context – Nanotechnology in the World

Government investments 1977-2003

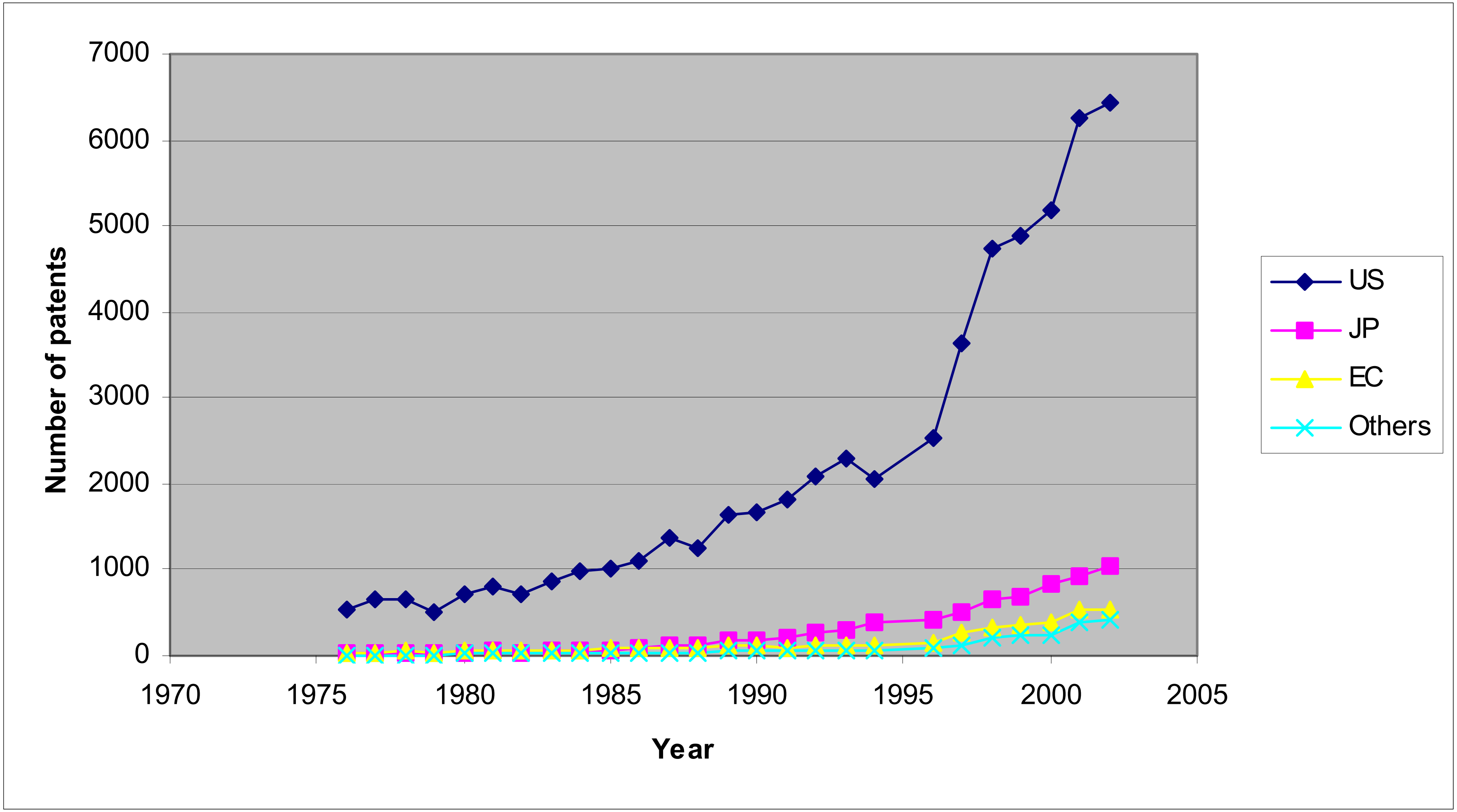


Note:

- U.S. begins FY in October, six months in advance of EU & Japan (in March/April)
- U.S. does not have a commanding lead as it had in other S&T megatrends, such as BIO, IT, space exploration, nuclear; U.S. ~ 35% in 2000, ~ 25% in 2003

Nanotechnology patents per region (NSF, 2003)

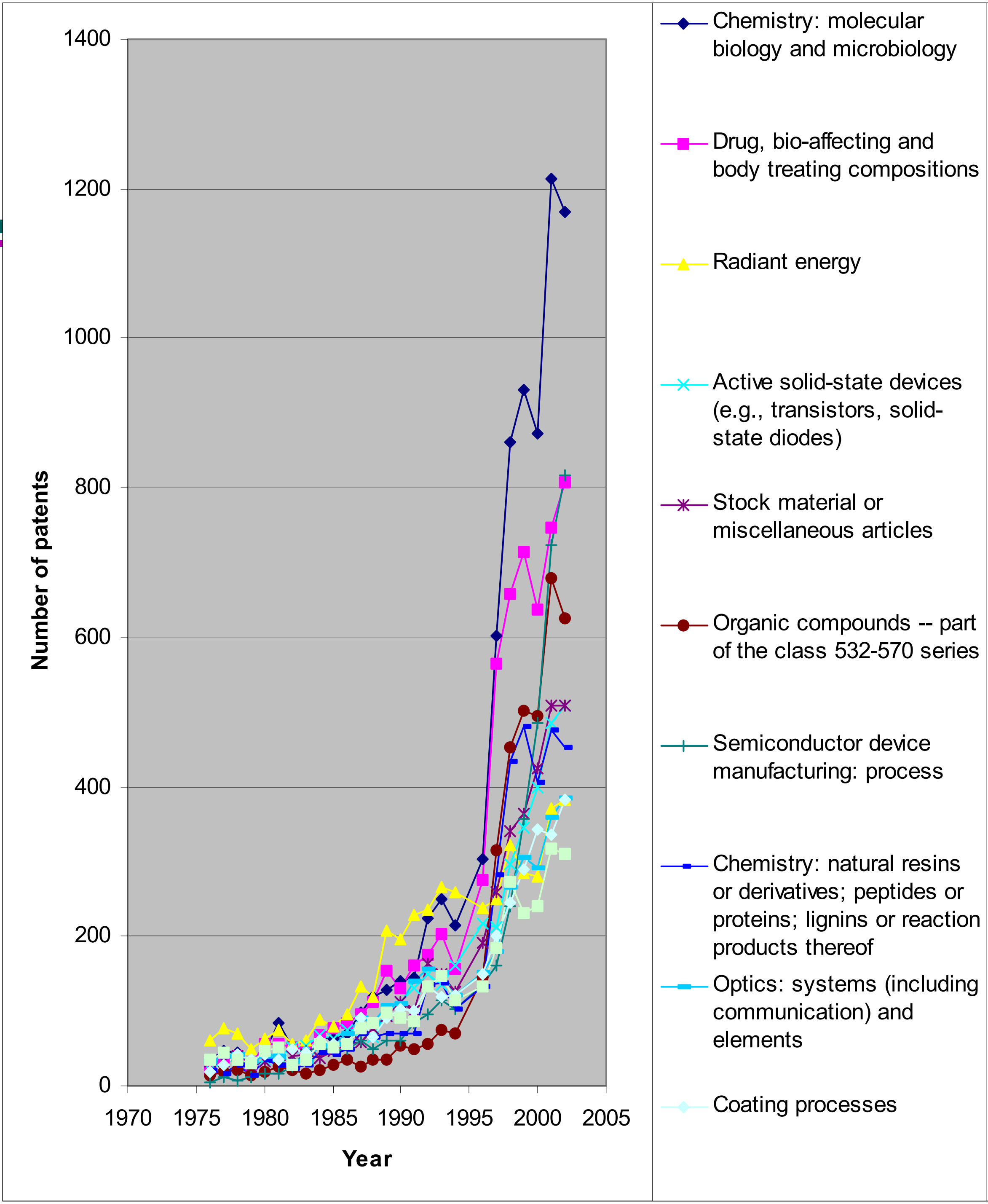
Searched by keywords at USPTO : nano*, atomic force microscop*, atomistic/molecular simulation, biomotor, molecular device, molecular electronics, molecular modeling, molecular motor, molecular sensor, quantum computing, quantum dot*, quantum effect*, scanning tunneling microscop*, selfassembl*



www.nsf.gov/nano (from J. of Nanoparticle Research, 2003)

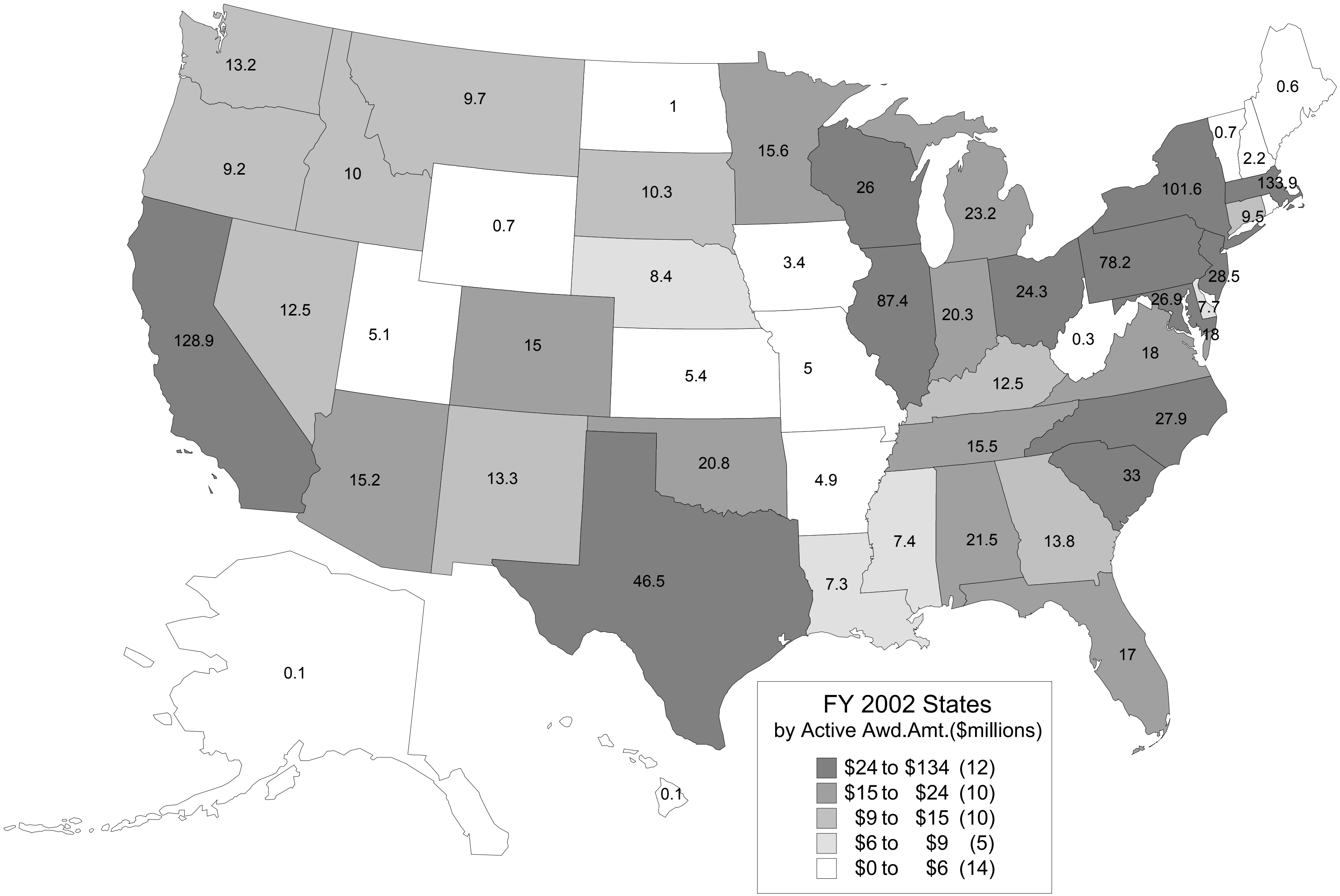
MC. Roco, 9/10/03

Technology field analysis by year



www.nsf.gov/nano (Longitudinal Nanotechnology Patent Analysis, from J. of Nanoparticle Research, 2003)

Geographical distribution (Ex: NSF awards, FY 2002)



Education and Training

- **Integrated Research and Education - Make Every Lab a Place of Learning** (over 6,000 trained per year)
- **Curriculum development**

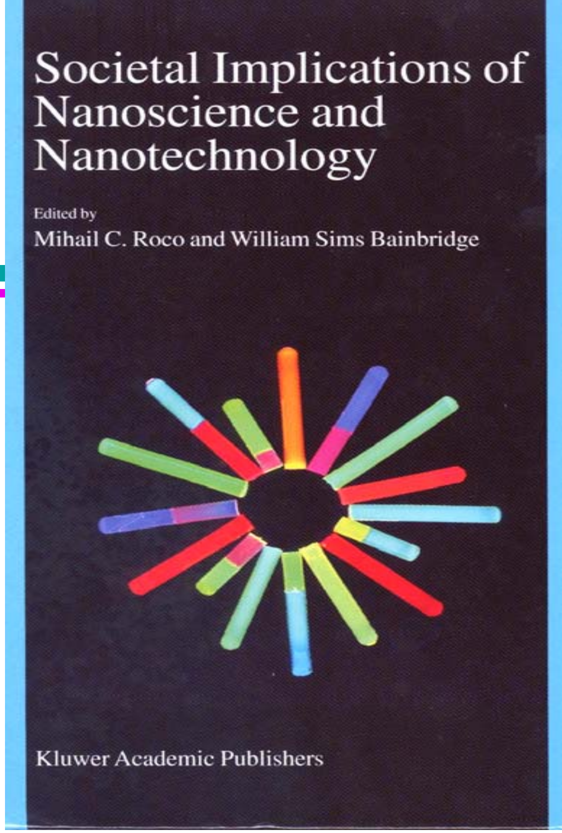
  New courses, 8 IGERT, Nanotech Undergrad Education
- **Education and outreach programs**

  from K-12 to G; includes NSEE; science museums
- **International education opportunities**

  young researchers to Japan and Europe; REU sites; attend courses abroad; PASI - Latin America, NSF-E.C.; bi-lateral workshops and exchanges

Societal Implications: Follow-up of the September 2000 report

- Make support for social, ethical, and economic research studies a priority:
  (a) New theme in the NSF program solicitations;
  (b) Centers with societal implications programs;
  (c) Initiative on the impact of technology, HSD
- NNCO – communicate with the public and address unexpected consequences
- Basic reference for the interaction with the public
- Taking faster advantage of the benefits
- Converging technologies from the nanoscale
- International workshop with EC (2001); links to Asia

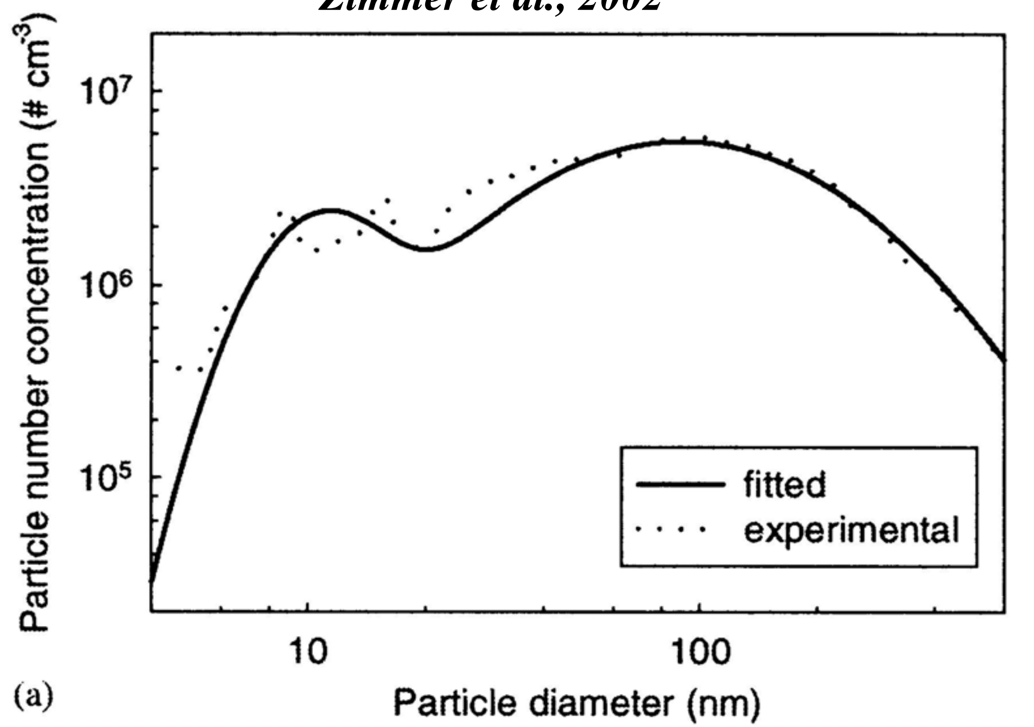


http://nano.gov

Environmental real issues: combustion, welding, water filtration, cell behavior, etc. and media highlights

Racette et al., 2001:
Welding-related Parkinsonism

Zimmer et al., 2002



Regional alliances

- **Nanotechnology Alliance in Southern California** www.larta.org/Nano
- **Nanotechnology Franklin Institute, Pennsylvania** www.sep.benfranklin.org/resources/nanotech.html
- **Texas Nanotechnology Initiative** www.texasnano.org
- **Virginia Nanotechnology Initiative** www.INanoVA.org
- **Denver Nano Hub** www.nanobusiness.org/denver.html
- **Silicon Valley, San Diego and Michigan Nano Hubs** May 2002
- **Massachusetts Nanotech Initiative (MNI)** Jan. 2003
- **Connecticut Nanotechnology Initiative (CNI)** Feb. 2003

NSET/NNCO sponsors series of regional research providers / industry / business meetings for networking, www.nano.gov

Others in partnerships in sight: regional; by NanoBusiness Alliance

W**orkshop NNI-regional and state alliances – September 2003**

State participation

Illustrations from 20 states

CA	California NanoSystem Institute	$100M/ 4 yrs
NY	Center of Excellence in Nanoelectronics; Albany Center	$50M, $400M/ 5 yrs
IL	Nanoscience Center (NU, U III, ANL)	$63M
PA	Nanotechnology Center	$37M
GA	Center at Georgia Tech	$25M
IN	Nanotechnology Center	$5M
TX	Nanotechnology Center	$0.5M over 2 yrs
SC	NanoCenter	$1M
AZ	Nanobio research	$5M for 20 years
NM	Consortium University of NM and National labs	
NJ	Support at NJIT and future nanophotonics consortium	
FL	Center at the University of South Florida	
OK	Nano-Net (~$3M/yr for 5 years)	

- OH (support Center $27M in Columbus), TN ($24M), Louisiana, CT, MA, VA, AZ

Congressional bills on nanotechnology (2004-2008)

NNI

- *Bill passed in the House:*

  H.R.766: "Nanotechnology R&D Act of 2003",

- *Draft Bill pending in the Senate*

  *189 "**21st Century Nanotechnology R&D Act**"*
  5-year "National Nanotechnology Program"

NNI challenges

- Need for coherent 5-10 year programs
- Horizontal versus vertical S&T development
  0.7% (on basics) versus 5% (plus precompetitive R&D) of US R&D budget
- Strengthening the partnership with industry;
  commercialization and competitiveness issues
- Collaboration and synergism among agencies
- Long-term R&D vision focused on interdisciplinary research and education, development of infrastructure, and broad societal implications
- Need for bold system-oriented programs, focused on topics such as: the new catalyst, new transistor, conditioning the cell
- International collaboration and competition